OPERATIONAL UTILIZATION OF WEATHER SATELLITE DATA FOR INPUT TO NUMERICAL ANALYSIS AND PREDICTION

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THESIS

Operational Utilization of Weather
Satellite Data for Input to Numerical
Analysis and Prediction

by

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ABSTRACT

The results of techniques and procedures used to evaluate the utility of satellite observations for enhancing the accuracy and detail of numerical analyses in sparse-data areas are presented. The experiments employed statistically-derived and subjective interpretations from video and infrared satellite data, for the purpose of modifying Fleet Numerical Weather Central's operational surface, 500- and 300-mb analyses. The resulting satellite-modified analyses for six synoptic times, in the period 11-14 March 1971, presents an implementation of satellite input to numerical analyses and prediction. The technology demonstrated here is offered as a guide to the man-machine approach to extra-tropical analysis as performed by major numerical weather centers.

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ABBREVIATIONS

AFSC	Air Force Satellite Center, Sunnyvale, California
ATS	Applications Technology Satellite
EPRF	Environmental Prediction Research Facility, Monterey, California
ESSA	Environmental Science Services Administration
FAMOS	Fleet Applications of Meteorological Observations from Satellites
FNWC	Fleet Numerical Weather Central, Monterey, California
FOFAX	Forecasters Facsimile Circuit
FWC	Fleet Weather Central
FWF	Fleet Weather Facility
IR	Infrared
ITOS	Improved TIROS Operational Satellite
NAFAX	National Facsimile Circuit
NESS	National Environmental Satellite Service
NESC	National Environmental Satellite Center
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate School, Monterey, California
NWRF	Navy Weather Research Facility (redesignated EPRF)
NWSED	Naval Weather Service Environmental Detachment
PE	Primitive Equation
PMR	Pacific Missile Range, Point Mugu, California
SCC	Spiral Cloud Center
SINAP	Satellite Input to Numerical Analysis and Prediction
SIRS	Satellite Infrared Spectrometer
TIROS	Television Infrared Observation Satellite

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I. INTRODUCTION

Ever since the first weather satellite was put into orbit in April 1960, meteorologists have searched for ways and means of converting the observations into a form compatible with the numerical, statistical and manual techniques employed by analysis and forecast centers at every level of operation. Of particular interest has been the utilization of the satellite-observed cloud patterns and types for the purpose of enhancing the pressure (height), wind and temperature fields at sea level and selected pressure surfaces in the troposphere and stratosphere. This study concentrates on the problem of using satellite observations to modify the analysis of pressure in sparse-data areas, based only on conventional data.

In particular, the objectives of the study are:

1) To further demonstrate the potential of video and infrared satellite observations to increase the accuracy of analysis of the mass and wind fields.

2) To apply and extend existent techniques for satellite input to analysis and prediction (SINAP) in such a way as to be operationally compatible with the mission of the quality control section of the Navy's Fleet Numerical Weather Central, Monterey, California.

II. BACKGROUND

The input of satellite data into operational numerical analysis and prediction schemes continues to be of major concern to major national and international analysis centers, such as FNWC, which now possess the capability for enhancement of the data base using weather satellite observations. Several approaches to the problem, hereafter called SINAP (satellite input to numerical analysis and prediction), have been made by various researchers.

Four methods for SINAP were considered by Mantei and Workman in a prior Naval Postgraduate School thesis [3]. The four methods involve: 1) use of vector cloud-motions from satellite time-lapse photographs as winds; 2) use of statistically-derived pressure-temperature soundings from satellite infrared spectrometer (SIRS) radiance observations; 3) subjective changes to analyses based on conventional data, as a function of interpretation of video and infrared (IR) weather satellite observations; and 4) use of statistically-derived 500-mb heights from satellite-observed cloud patterns. The last two of these methods were considered to be in most need of further tests and evaluation. Therefore, they were selected as the basis for this study. A brief discussion of the background of these methods follows.

A. SUBJECTIVE CHANGES TO THE ANALYSIS FROM THE INTERPRETATION OF VIDEO AND INFRARED WEATHER SATELLITE OBSERVATIONS

Weather satellites continue to be an ever increasing source of data over sparse-data areas of the world. Since 1960, when the first meteorological satellite video pictures were received, research has been conducted to improve the interpretation of these data. In recent years, the daily mapping of the IR and video picture data has provided a new dimension to satellite observations. Now, by using both IR and video data, information on both horizontal and vertical distributions of clouds can be determined.

Many researchers from various organizations have made numerous studies of the relationships between satellite-observed cloud patterns and various parameters important in weather processes. Lists of rules and illustrations have been prepared and are beyond the scope of this study to present here. The reader is especially directed to [1, 11 and 12] for video and to [13] for IR imagery interpretations.

It should be pointed out that if the maximum value of these data are to be realized, correct interpretation of the cloud photographs is essential. Thus, it is of utmost importance that the photo interpreter have an adequate academic and operational background in the field of meteorology. The subjective role in using satellite observations will become evident in the discussion that follows.

B. STATISTICALLY-DERIVED 500-MB HEIGHTS FROM SATELLITE-OBSERVED CLOUD PATTERNS

A technique to derive 500-mb heights from cloud pattern information was developed by Nagle and Clark at NESC in 1968 [4, 14]. This technique was further refined by Nagle and Hayden at NESS in 1969 [7] for operational use at NMC.

The technique as it applies to this study consists of the following procedures. The 500-mb analysis is segregated into several fields by a pattern separation technique. Two of the fields produced by this technique are the SR (equivalent to a space-mean field) which depicts the long-wave pattern, and the SD (equivalent to a disturbance field) which depicts the short wave features. These fields are additive, that is

$$Z = SR + SD \tag{1}$$

where Z is the 500-mb height.

The SR field is assumed to be conserved with time and thus is regarded as a perfect prognosis. The SD field corresponds closely to the 500-mb relative vorticity field with the algebraic sign reversed. In particular, the SD zero line approximates the zero relative vorticity line.

The objective is to produce an optimum 500-mb analysis by using satellite cloud pictures to correct the SD field. The first step is to calculate the 500-mb height at centers of positive relative vorticity as implied by the cloud patterns valid at approximately the same time as the 500-mb analysis. Nagle has shown that relative vorticity centers

given by SD fields closely coincide with the location of spiral cloud centers (SCC). The magnitude of the SD minimum value at the spiral cloud center, as obtained from the solution of a regression equation, is a function of 1) the latitude of the SCC (LAT), 2) the maximum diameter of the SCC (MAXDI), 3) the amplitude of the SCC cloud system (CDAMP), and 4) the Laplacian of the SR field at the SCC (LAPSR).

The regression equation (SCC Method) is given by

$$21.5 + (-1.7)\mathrm{LAT} + (-10.4)\mathrm{MAXDI} + (-1.0)\mathrm{CDAMP} + (-2.1)\mathrm{LAPSR} = \pm(\mathrm{SD})\mathrm{m} + (\mathrm{SR})\mathrm{m} = (\mathrm{Z500})\mathrm{m} \qquad (2)$$

where (SD)m is the computed SD height at the SCC in meters, (SR)m is the SR height at the SCC in meters, and (Z500)m is the estimated 500-mb height in meters.

An alternate regression equation, used when cloud development is poor, is given by

$$-53.5 + (-1.03)\mathrm{LAT} + (-1.65)\mathrm{LAPSR} = \pm(\mathrm{SD})\mathrm{m} + (\mathrm{SR})\mathrm{m} = (\mathrm{Z500})\mathrm{m} \qquad (3)$$

Hydrostatic height extrapolations were made as a check on these computations.

The regression equations are shown in worksheet form in [3]. Examples of spiral cloud systems, with the maximum diameter and amplitude defined, are shown in Fig. 1, where the heavy solid lines delineate the leading edge of the cloud systems and the point T is where the 500-mb trough intersects the frontal clouds. The length of the line M-M is the maximum diameter (MAXDI) and the distance from the

center of the spiral S to the point T is the amplitude of the cloud system (CDAMP).

The second part of the procedure is to obtain other height values surrounding the SCC to form the basis of an analysis of the small scale system. This is accomplished by adjusting the SD zero line from a subjective interpretation of the cloud patterns. Various rules have been developed from studies relating cloud patterns to the position of the 500-mb SD zero line. Figure 2 shows several examples of the relationships between cloud patterns and the 500-mb SD field. Further amplification of these relationships can be found in [9]. Basically, the concept is to identify the areas of positive relative vorticity at 500 mb. This is made possible by the close correspondence between changes in cloud form and the location of the axis of maximum wind at 500 mb. Having established the position of the SD zero lines from the satellite picture (mosaic), 500-mb heights are read from the SR field at points where the zero lines intersect SR contours.

The computed heights at spiral cloud centers and the heights along the zero lines surrounding these centers, coupled with the positions of ridges and trough lines determined from the cloud pictures, form the basis for a modified analysis of the 500-mb height field over the area of interest.

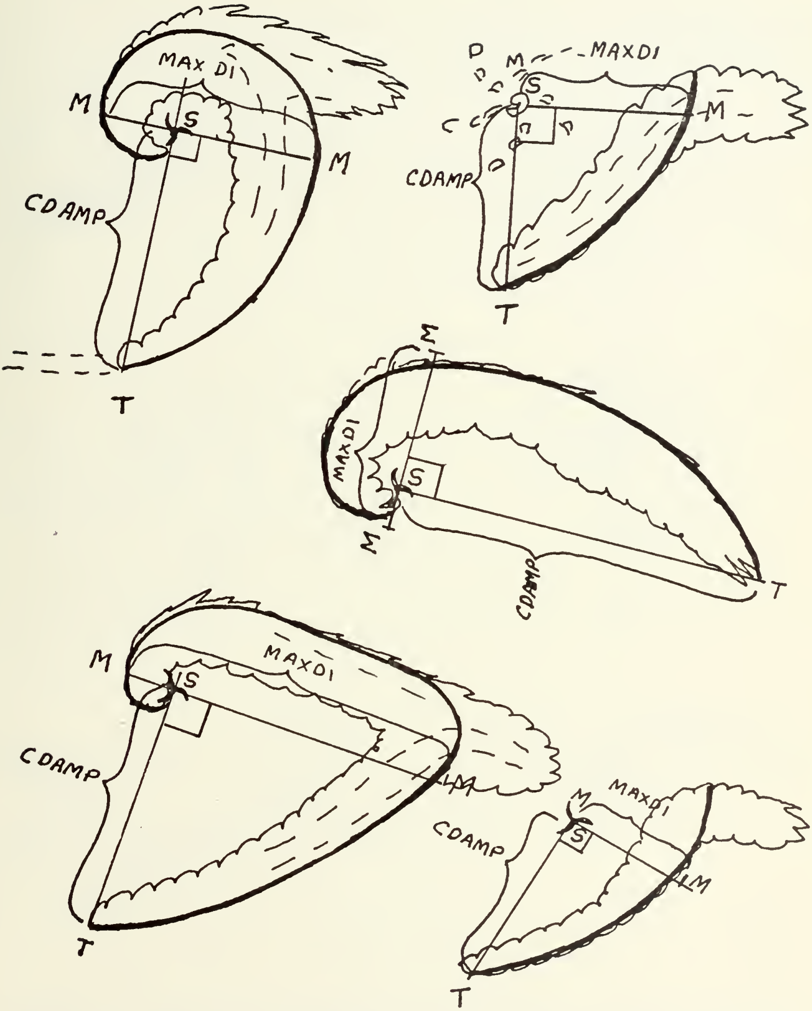

Figure 1. Examples of schematic cloud patterns illustrating the definition of maximum diameter (M-M) and the amplitude of spiral cloud systems (S-T).

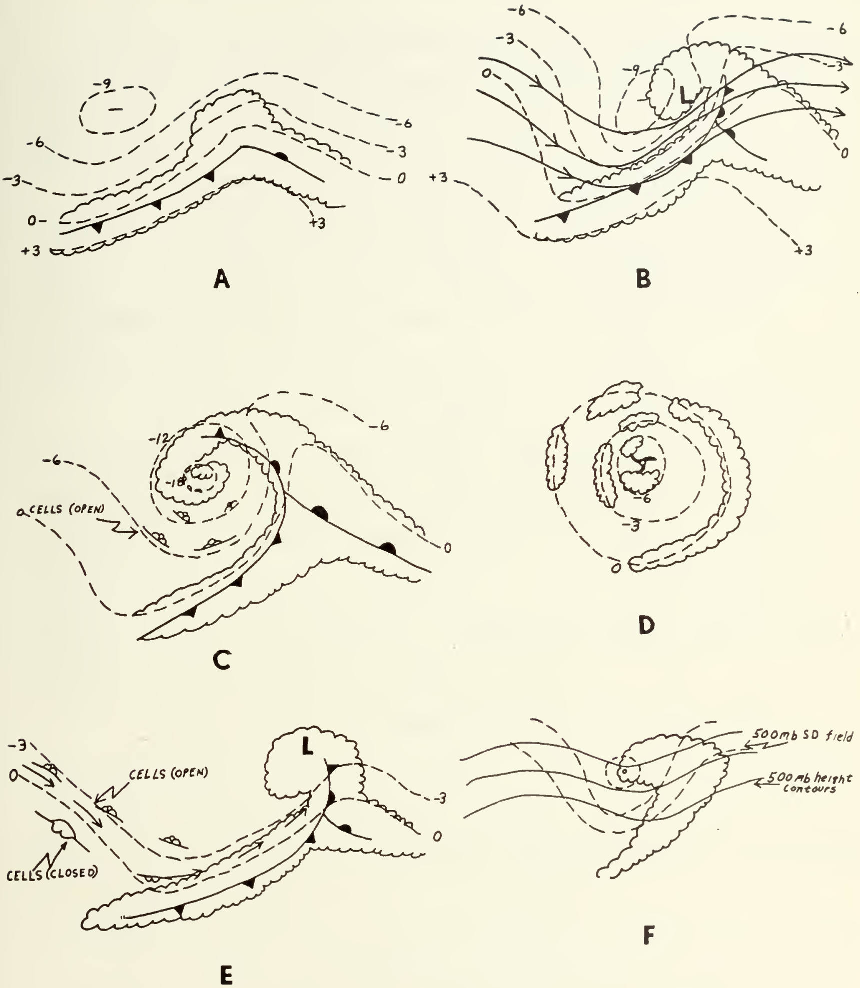

Figure 2. The relationship between cloud patterns and the 500-mb SD field [9].
A. Surface wave vs. SD field.
B. Occluded system with 500-mb flow and SD field.
C. Mature cyclone vs. SD field.
D. Dissipating cyclone vs. SD field.
E. Location of zero SD contour.
F. 500-mb SD flow vs. PVA MAX.

III. DATA SOURCES AND SELECTION OF STUDY PERIOD

The six upper air synoptic times from 1200 GMT 11 March through 0000 GMT 14 March 1971 were selected for the investigation for the following reasons.

1) Adequate data were readily available. An abundance of data had been collected for the previous study [3], a large part of which was not utilized. Additional work was suggested by Mantei and Workman in this meteorological area for which the surplus data could be used.

2) The full spectrum of cyclone development and decay was observed in the North Pacific Ocean over the period with more than one synoptic-scale system present at a time to provide contrast for modification techniques. Such a period was necessary to obtain sufficient results from modifications of a variety of stages of cyclone development over a period of optimum time.

3) Neither satellite-derived bogus data from FWF Suitland nor SIRS data from NMC (via FWF Suitland) entered the FNWC analyses during this period. Such a fortuitous event was necessary in order to clearly evaluate the results of satellite input.

4) The last two synoptic times from a previous study by Mantei and Workman [3], namely 1200 GMT 11 March and 0000 GMT 12 March 1971, were available and hence selected as a beginning to gain familiarity with the techniques and procedures to be used in modifications to the analyses.

This insured a sufficient time period for the case studies undertaken, but mainly it provided an overlap period to enable this investigator to gain familiarity with the procedures and techniques used. These dates also provided the opportunity to compare results.

5) An equal number of synoptic times were available for the use of video and IR satellite data. Only limited studies have been previously conducted using IR data as input to SINAP procedures.

Table I lists the satellite and conventional data sources used in this research. Individual acknowledgements are listed in [3]. However, the author also is indebted to each activity and the individuals in these organizations for their cooperation in making this data available to the Department of Meteorology, Naval Postgraduate School, Monterey, California.

TABLE I

Sources of conventional and satellite data.

A. Satellite Data

1. Video Pictures (ITOS 1, ESSA VIII):

FWC's Alameda, Pearl Harbor, Guam
FWF's Kodiak, Yokusuka, Sangley Point
NPS Monterey
PMR Pt. Mugu
NWSED's Moffett Field, Midway Island, Adak Island
AFSC Sunnyvale
NESS Suitland (Mosaics)

*2. IR Nighttime Data (ITOS 1):

NESS Suitland (Mosaics)

*3. Nephanalyses:

NESS Suitland (also available from FOFAX and NAFAX circuits)

B. Conventional Data

1. Surface and Upper Air Synoptic Data:

FNWC Monterey
NMC Suitland

2. Surface Analyses:

FNWC Monterey
FWC's Alameda, Pearl Harbor
NMC Suitland (FOFAX and NAFAX circuits)

3. Upper Air Analyses:

FNWC Monterey
FWC Pearl Harbor (Tropical)
NMC Suitland (FOFAX and NAFAX circuits)

4. Pattern Separation Analyses (SR and SD Contour Fields):

FNWC Monterey

*Collected and forwarded by Project FAMOS

IV. PROCEDURES AND RESTRICTIONS

The objectives of the procedures were to obtain the best possible analyses using all of the available satellite data. Conventional observations were considered reliable and inviolate unless clearly demonstrated otherwise.

The area of study was restricted to the North Pacific Ocean from the west coast of North America to approximately 160° E, between 25° N and 70° N, with emphasis on the sparse-data area between 30° N and 55° N where extratropical mid-latitude cyclones develop and traverse. All analyses were performed on a 1:30,000,000 scale (FNWC chart No. 4-P-1) polar sterographic projection, true at 60° N. The ITOS 1 IR and video mosaics, approximating the synoptic times, were enlarged to the 1:30,000,000 scale on the polar stero-graphic projection for compatability in analyses, especially for the Nagle-Hayden technique.

1) The operational 0000/1200 GMT surface, 500 mb, 500-mb SR and 300-mb analyses were considered the first guess fields.

2) All available satellite cloud patterns pictures were reviewed to gain a familiarity between the cloud patterns and synoptic systems. ATS-1 photos taken at approximately 24 minute intervals from 1800-0200 GMT were studied for continuity and to detect changes. The only satellite photos available for the 1200 GMT synoptic period were the ITOS IR nighttime mosaics taken between 1000 GMT and 1600 GMT over the Pacific Ocean region.

3) Using the operational 0000/1200 GMT 500-mb SR analysis, spiral cloud centers and zero vorticity (SD zero-line) lines obtained from the satellite views were plotted and the Nagle-Hayden statistical computations performed.

4) The FNWC surface and 500-mb analyses were subjectively changed to conform to the major features derived from the satellite data. Fronts were entered on the surface analysis.

5) The FNWC 300-mb analysis was subjectively changed to agree with the features on the 500-mb analysis and the 300-mb analysis was used to check the gradients and locate maximum wind areas at 500 mb.

6) The intermediate 0600/1800 GMT surface analysis was used to improve the modification to the sea-level isobars.

After all modifications had been performed using the above procedures, a 1000/500-mb thickness analysis for each synoptic time was manually performed on the MOD and UNMOD ANALS.[1] They were superimposed on the same chart with the surface fronts added. In this way comparisons could be readily made between the two analyses and a proper evaluation of the Nagle-Hayden techniques could be determined.

No attempt was made to fabricate reports from the manually-modified analyses for the purpose of generating

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[1]In the foregoing discussion, the following terms are used:
UNMOD ANAL -- analysis derived from conventional data only.
MOD ANAL -- analysis derived from conventional data and satellite observations.

numerical modified analyses. Rather, the emphasis was on the further evaluation of SINAP techniques and procedures, which could be used operationally at FNWC.

In some instances very minor modifications were made to the UNMOD analyses; such changes were not considered of sufficient importance to be discussed here. In general, these were made to provide better time and space continuity.

V. CASE STUDIES OF MODIFICATIONS TO ANALYSES

Synoptic times 1200 GMT 11 March through 0000 GMT 14 March 1971 were studied in detail, with modifications made to the respective sea-level pressure and 500-mb and 300-mb height fields.

The purpose of these case studies is to present a guide to SINAP based on a condensation of this investigator's experience and in particular to demonstrate procedures which a quality control group could use in modifying numerical analyses over data-sparse areas using satellite data as input.

Six figures, with two figures per page, showing analyses follow immediately after the discussion and description of the modifications made in each case study. Each figure in the set of six always appears in the same sequence after each case study. A detailed description of each figure will be presented here to eliminate repeated descriptions.

TOP, FIRST FIGURE PAGE

1) Digitized cloud mosaic and sea-level pressure UNMOD ANAL

The UNMOD ANAL is superimposed on the satellite mosaic. The sea-level isobars are drawn at an 8-mb interval with intermediate isobars (dashed) for clarification. The central pressure and isobars are labeled in whole millibars with either the 9 or 10 deleted. Central pressures are included if they appeared on the FNWC UNMOD ANAL.

BOTTOM, FIRST FIGURE PAGE

2) <u>Surface MOD ANAL</u>

The sea-level isobars on the MOD ANAL are labeled in the same manner as on the UNMOD ANAL. Surface fronts are shown on the MOD ANAL, using conventional symbology. They were placed according to the cloud patterns, surface data and past history.

TOP, SECOND FIGURE PAGE

3) <u>Digitized cloud mosaic, 500-mb UNMOD ANAL</u>

The UNMOD ANAL is superimposed on the satellite mosaic with the zero line of the 500-mb SD field appearing as a dashed white line. The 500-mb height contours are drawn for every 120 meters with occasional dashed intermediate contours for clarification of pattern or gradient. The contours and height centers are labeled in decameters. Height centers are included if they appeared on the FNWC UNMOD ANAL.

BOTTOM, SECOND FIGURE PAGE

4) <u>500-mb MOD ANAL</u>

The MOD ANAL is labeled in the same manner as the UNMOD ANAL. In addition, the modified SD zero line is superimposed on the 500-mb MOD ANAL. Along the zero lines are plotted heights in decameters, with the first digit deleted.

TOP, THIRD FIGURE PAGE

5) <u>1000/500-mb thickness UNMOD and MOD ANALS</u>

The UNMOD ANAL appears as solid lines while the MOD ANAL appears as dashed lines. They are included on the same chart for comparison purposes. The heights are analyzed at 60 meter intervals and are labeled in decameters. The fronts from the surface MOD ANAL are superimposed.

BOTTOM, THIRD FIGURE PAGE

6) <u>300-mb UNMOD and MOD ANALS</u>

The 300-mb height contours are drawn at 120 meter intervals with the UNMOD ANAL shown as solid lines, while the MOD ANAL is dashed. Central heights and contours are labeled in decameters.

A. 1200 GMT 11 MARCH 1971 ANALYSES

The 1200 GMT surface analysis of the Pacific Ocean is normally a function of sparse data due to the local time (near midnight) over the region. Thus, most ships neither record nor transmit observations. Based primarily on the satellite mosaic of ITOS 1 IR, the following modifications were made to the surface and 500-mb analyses.

Figure 3 shows the UNMOD sea-level pressure analysis superimposed on the satellite mosaic. Only minimal modification is suggested by the cloud patterns. Figure 4 shows the MOD surface analysis. The low center near 56° N, 178° E was moved northwest to 57° N, 172° E and deepened slightly to agree with the cloud vortex. The white cloud areas completely encircle the center of the cloud vortex near 45° N, 138° W, indicating the cyclone has reached full maturity and should begin to fill. Slight deepening was also introduced here. The cloud vortex near 42° N, 169° E is the dominant feature in the western portion of the photograph. The center is faintly discernible with a large, extremely wide dry tongue extending northeast. The stage of development of the center is early maturity. Noting the lack of surface data with a flat pressure gradient but the strong vertical motion of the system, as indicated by the bright white cloud areas of the IR mosaic, the sea-level pressure was lowered to 1003 mb. The cloud pattern and surface data supported a closed 1015-mb low center near 42° N, 152° E.

Figure 5 shows the FNWC 500-mb UNMOD analysis superimposed on the satellite mosaic. The zero line of the 500-mb SD field is shown by the white dashed line. The discrepancies between the zero line and the cloud patterns are rather typical. The general pattern of the zero line reflects the systems which appear in the cloud patterns but there are errors in amplitude and location. For example, near 130° W from 40-50° N, the zero line is located too far south and east. Near 40° N, 150° W there is an indication in the cloud pattern that a PVA MAX is beginning to form, but the SD zero line indicates negative vorticity in the area. Near 40° N, 170° E the orientation of the zero line agrees very well with the frontal position but the location of the zero line is in error. The modified analysis is shown in Fig. 6. This analysis contains the heights along the zero line and at three vorticity centers computed from the regression equations (see Section II). These systems are located at 46° N, 140° W; 49.5° N, 165° W; and 44° N, 168° E. The heights computed at these centers deviated from the FNWC analysis by -120, -80, and -90 meters, respectively. The areas of adjustment in the analysis are associated with the three vorticity centers. The SD zero line and 500-mb ridge off the west coast of the United States were adjusted westward to fit the cloud pattern of the mature cyclone with the zero line moved south of the PVA MAX forming in the cyclone's southwest quadrant. The 500-mb trough near 165° W had been moved too rapidly east

and smoothed prematurely from the previous analysis. This was adjusted and deepened to fit the enhanced cumuliform clouds in the area just east of 45° N, 165° W. The 500-mb ridge near 180° W was enhanced slightly to accomodate greater anticyclonic flow apparent from the cloud pattern. A closed low was introduced at 44° N, 168° E due to the stage of development and to agree with the surface low positioned to the southeast.

Figure 7 shows the 1000/500-mb thickness analyses for the MOD (dashed) and UNMOD (solid) ANALS with the surface fronts superimposed. The modified thickness pattern shows improved agreement with the surface front over the eastern Pacific. The thickness ridge was advanced just east of the vortex due to the increased height and height gradient on the 500-mb MOD ANAL. Most changes in the thickness pattern are a result of the changes made at 500 mb since the surface MOD ANALS usually require less change. Although there was less change in the thickness pattern over the western Pacific near 40° N, 175° W, some improvement may be noted from the enhancement of the thickness ridge over the surface frontal system. The thermal troughs are in good agreement with the location of the 500-mb troughs on the MOD ANALS.

Figure 8 shows the 300-mb MOD (dashed) and UNMOD (solid) ANALS. The 300-mb analysis was modified by deepening the trough near 140° W, relocating the trough slightly near 165° W, and enhancing the ridge near 180° W. In general,

modifications at 300 mb were made to agree with the 500-mb MOD ANAL, with the largest change being about 60 meters.

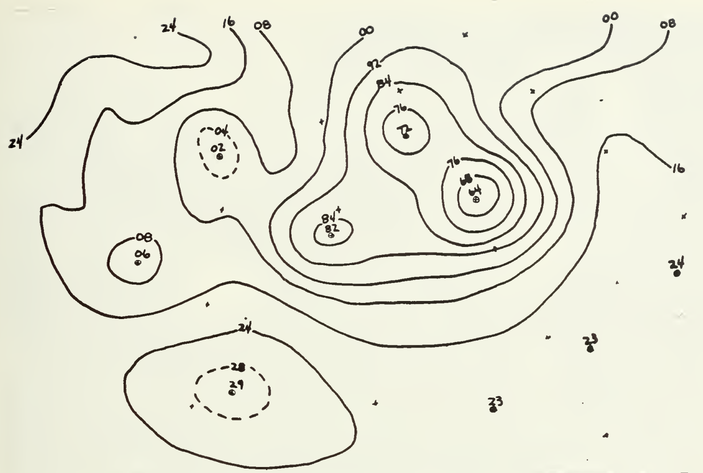


FIG. 3 PHOTO OF ITOS IR MOSAIC AND SEA LEVEL PRESSURE UNMOD ANAL
1200 GMT 11 MARCH 1971

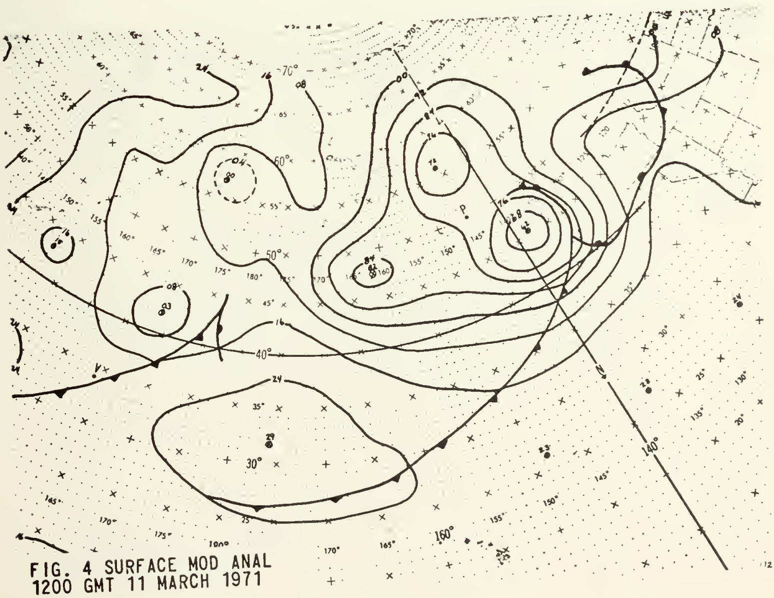


FIG. 4 SURFACE MOD ANAL
1200 GMT 11 MARCH 1971

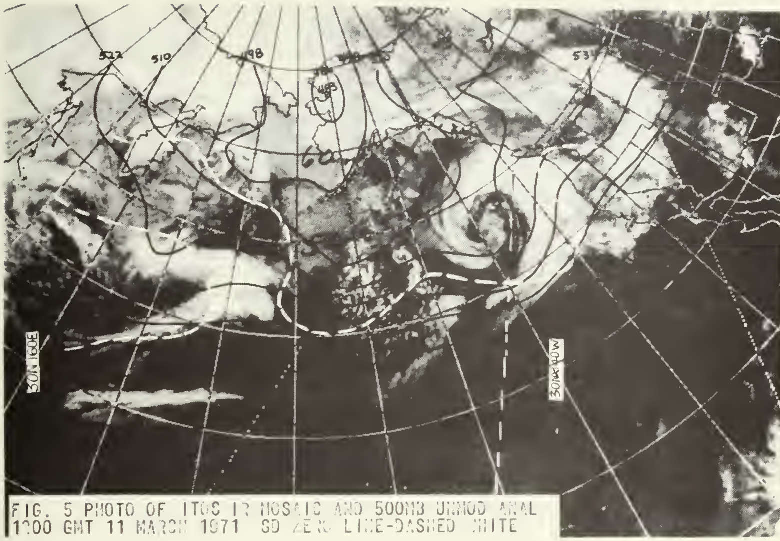


FIG. 5 PHOTO OF ITOS IR MOSAIC AND 500MB UNMOD ANAL
1200 GMT 11 MARCH 1971 SD ZERO LINE-DASHED WHITE

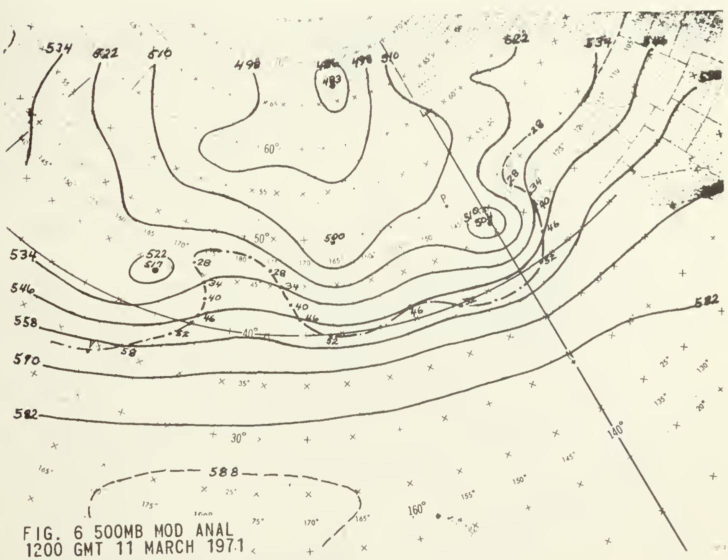


FIG. 6 500MB MOD ANAL
1200 GMT 11 MARCH 1971

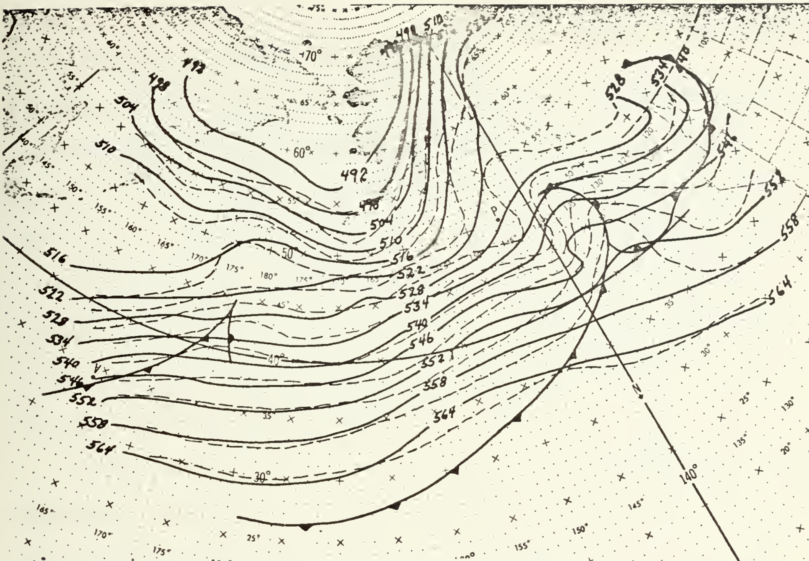


FIG. 7 1000-500MB THICKNESS ANALYSES —UNMOD ANAL
1200 GMT 11 MARCH 1971 ---MOD ANAL

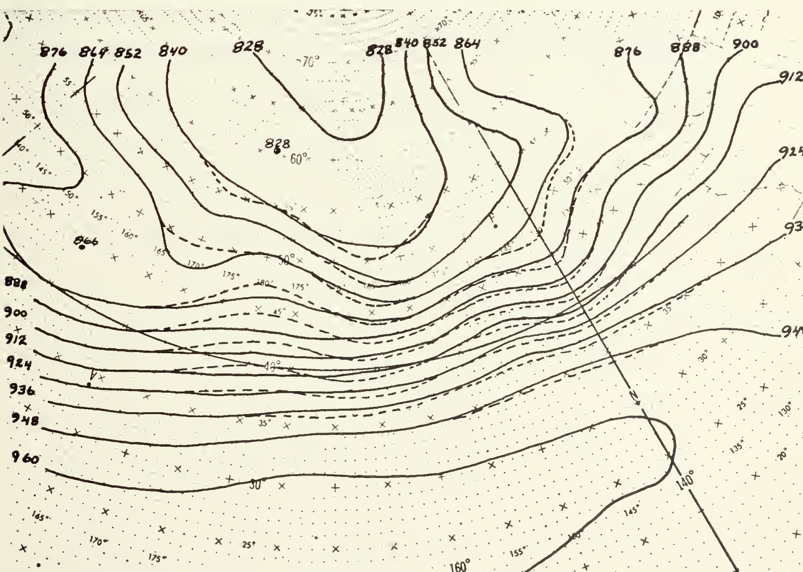


FIG. 8 300MB ANALYSES —UNMOD ANAL
1200 GMT 11 MARCH 1971 ---MOD ANAL

B. 0000 GMT 12 MARCH 1971 ANALYSES

There was excellent video coverage along with increased surface data at this particular synoptic time over the North Pacific Ocean. The 0000 GMT surface analysis over the area is based on a maximum number of ship reports because it is near midday over this region and therefore corresponds to the routine broadcast day. The video pictures at this time are the basis of the following modifications to the surface and 500-mb analyses.

Figure 9 indicates little change to the UNMOD sea-level pressure analysis over the eastern portion of the area but the cloud vortex near 45° N, 177° E doesn't fit the analysis. This low center is adjusted westward from 46° N, 179° W to 45° N, 177° E in Fig. 10. Some major features emphasized by the video photograph are as follows. The cyclone approaching the west coast of North America is fully matured and should begin to fill as the cold air in the dry tongue completely encircles the center. The PVA MAX has developed rapidly and moved eastward to near 40° N, 140° W with an associated bulge of the cold front near 35° N, 140° W. A wave may be expected to develop on the front during the next 12 hours. The low near 45° N, 150° W has nearly disappeared from the surface analysis as it continues to fill rapidly, remaining only as a weak trough in the northwesterly flow of the mature cyclone.

Figure 11 shows that the 500-mb SD zero line reflects the general cloud patterns but the error in positioning has

increased in certain areas. The cloud vortex near 47° N, 177° E is associated with the zero line crossing the frontal areas of the system and extending southeast into the 500-mb ridge. This is perhaps a reflection of the incorrect surface analysis which positioned the surface low near 179° W. The zero line also extends southeast through an area of stratocumulus from 53° N, 165° W to near 42° N, 155° W. It runs north of the PVA MAX, placing the latter in an area of negative vorticity. The PVA MAX should lie near a 500-mb short wave trough which is an area of positive vorticity. The modified analysis (Fig. 12) shows the corrections applied in this areas. The SD zero line and the 500-mb trough along the west coast of North America were moved west to agree with the cloud pattern, while the low center was deepened by 70 meters and moved southward to provide a more vertical structure of this mature system. The trough near 155° W was moved west in agreement with the weak surface trough. The orientation of the ridge near 170° W was modified from north-west-southeast to more nearly north-south, with corresponding changes made to the trough associated with the low near 47° N, 177° E. The central value of the low was deepened 60 meters in agreement with the deepening at the surface.

Figure 13 shows that the east Pacific surface frontal system is located near the thermal trough of the UNMOD 1000/500-mb thickness analysis. There was significant improvement in positioning this frontal system by the

modifications at 500 mb. The continuity in the MOD ANAL is also good from the previous analysis. There was some improvement in the thickness pattern over the system near 175° W but further change appears desirable. The MOD ANAL introduced some curvature into the thickness pattern here as noted by the increase in thickness over the frontal zone. Again the 500-mb MOD ANAL shows good agreement with the thermal troughs.

Figure 14 shows that corresponding changes were made at 300 and 500 mb. The 300-mb trough and ridge positions were aligned with those at 500 mb. The trough near 135° W was deepened a maximum of nearly 200 meters while the maximum changes in the trough near 155° W and the ridge near 170° W was about 120 meters.

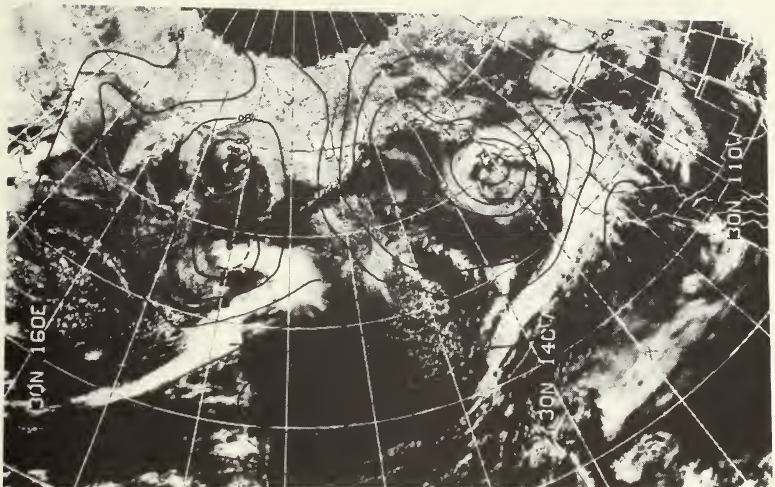


FIG. 9 PHOTO OF ITOS 1 VIDEO MOSAIC AND SEA LEVEL PRESSURE UNMOD ANAL
0000 GMT 12 MARCH 1971

FIG. 10 SURFACE MOD ANAL
0000 GMT 12 MARCH 1971

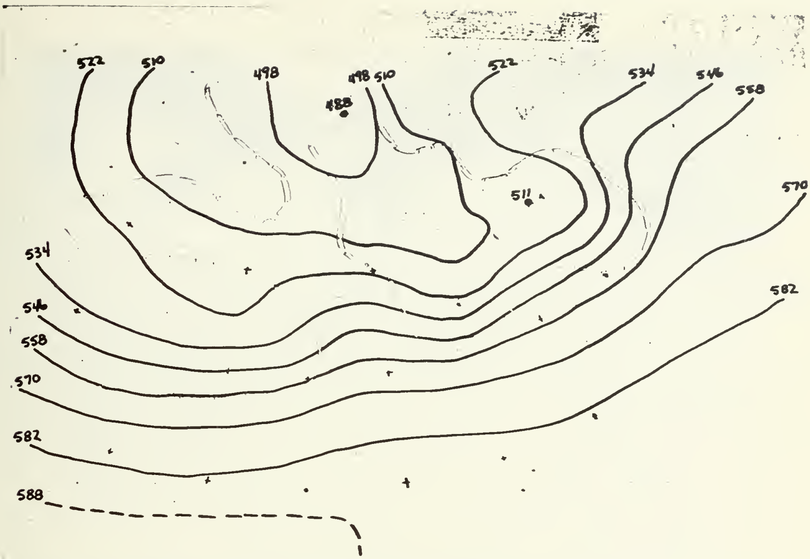


FIG. 11 PHOTO OF ITOS 1 VIDEO MOSAIC AND 500MB UNMOD ANAL
0000 GMT 12 MARCH 1971 SD ZERO LINE-DASHED WHITE 12/00

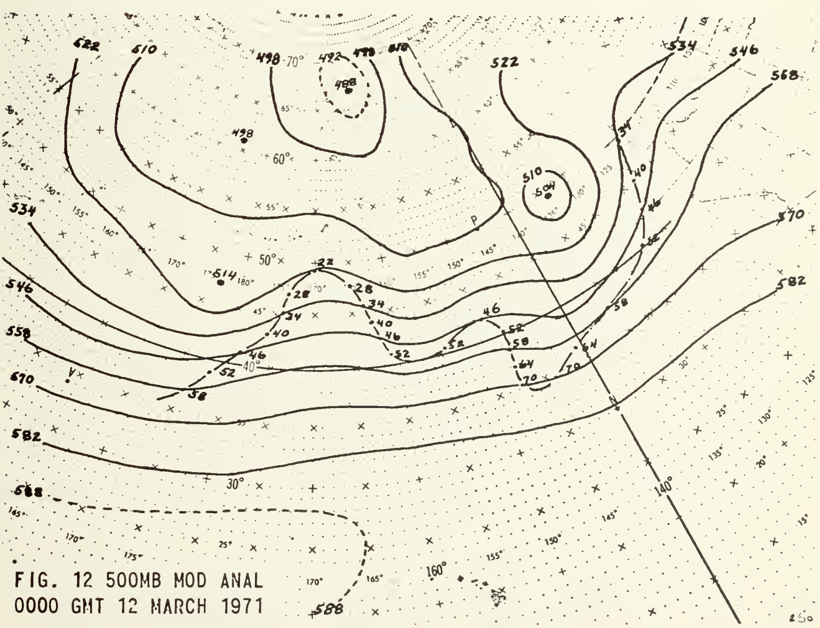


FIG. 12 500MB MOD ANAL
0000 GMT 12 MARCH 1971

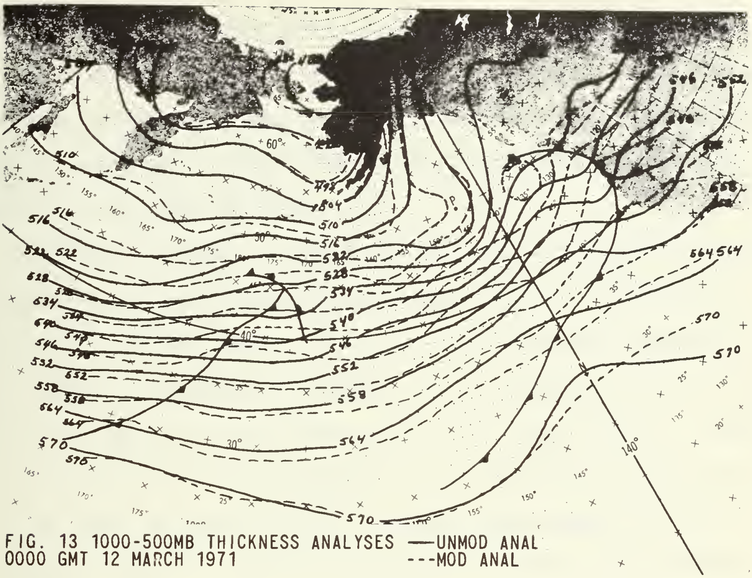


FIG. 13 1000-500MB THICKNESS ANALYSES —UNMOD ANAL
0000 GMT 12 MARCH 1971 ---MOD ANAL

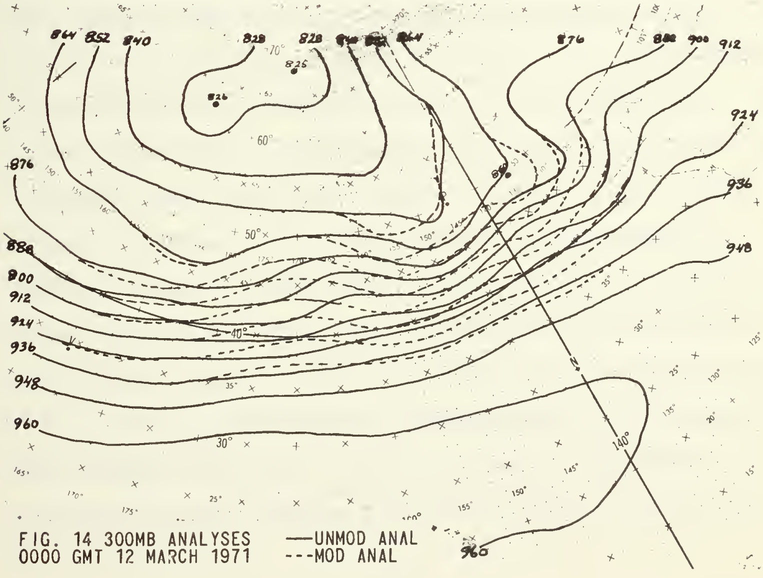


FIG. 14 300MB ANALYSES —UNMOD ANAL
0000 GMT 12 MARCH 1971 ---MOD ANAL

C. 1200 GMT 12 MARCH 1971 ANALYSES

The photo mosaic of ITOS 1 IR nighttime viewing was the primary source for the following changes to the surface and 500-mb analyses. There were a few more surface reports than at 1200 GMT 11 March 1971.

Figure 15 shows a cloud vortex near 47° N, 173° W with a small area of bright white clouds in the eastern semi-circle. A grey area, similiar to the wide dry tongue on the previous analysis, appears to be separating this vortex from the bright cloud mass to the east near 160° W. There is indication of the formation of a new cloud vortex near 47° N, 160° W thus limiting further development of the orginal vortex. The FNWC analysis for 0600 and 1800 GMT analyzed the central pressure of the surface low at 984 mb, yet it was left at 993 mb on the 1200 GMT analysis. The cloud patterns near the low center plus a ship report near 45° N, 177° W, reporting 995.1 mb, NW 40 kt, were the basis for deepening the central pressure to 986 mb.(See Fig. 16). The low center near 51° N, 132° W has filled slowly during its mature stage, yet large bands of bright white clouds are maintained indicating appreciable vertical motion. A wave has formed on the front near 35° N, 129° W, indicated by the bulge on the front and as predicted by the events on the previous analysis. The formation of a new PVA MAX near 40° N, 140° W is indicated by the presence of an enhanced comma-shaped cloud mass. There is also the indication of a possible PVA MAX forming near 40° N, 170° E. The 982-mb

low near 58.5° N, 146° W was based on surface reports and maintained from past history.

Figure 17 shows that the error in the 500-mb SD zero line is mainly one of amplitude. For example, the zero line is analyzed directly across the center of the bright white cloud pattern just north of 40° N, 160° W showing very little amplitude. This bright cloud pattern is not associated with a ridge along its leading edge as might be expected. The zero line extends eastward across the new PVA MAX near 40° N, 140° W then dips southeast of the wave along the northern California coast. The modified analysis, shown in Fig. 18 illustrates the desired changes indicated by the prominent cloud patterns. A 500-mb ridge is indicated by the anticyclonic curvature of the cloud mass near 160° W and the trough was deepened to the west to reflect the intensity of the low center near 48° N, 174° W. The weak short wave trough near 155° W on the previous analysis has moved rapidly toward the east into the long wave trough near 140° W, which is the longitude of the new PVA MAX. The center of the 500-mb low east of ship PAPA was moved slightly to the northeast for better vertical agreement with the surface low but the SINAP computation indicated no appreciable change in height. A -50 meter height difference was computed for the 500-mb low center near 174° W. The zero line was adjusted in the vicinity of the ridge near 160° W and the PVA MAX with open-celled clouds to the southwest, and then correctly positioned near

the forming wave along the front off the northern California coast. The position of the zero line surrounding the low near 48° N, 174° W was difficult to determine because of the possibility of a PVA MAX near 40° N, 170° E. But the pattern of open-celled clouds to the west of the low indicated a turn to the north.

Figure 19 shows that the UNMOD ANAL of the 1000/500-mb thickness is in somewhat better agreement with the surface frontal systems than on previous analyses. However, the MOD ANAL of the thickness shows definite improvements. The thickness pattern is improved over the developing wave near the northern California coast and the packing of thickness lines behind the cold front shows a more classic pattern. The thickness trough was deepened along 140° W which agrees with the position of the 500-mb trough on the MOD ANAL. The MOD ANAL increased the thickness ridge slightly over the frontal system near 165° W but further improvement in location appears desirable. A thickness trough appears north of 40° N near 178° W as a result of deepening the surface low and some deepening of the 500-mb trough in the area. The UNMOD ANAL shows the gross features but lacks the detail to properly identify developments that are taking place according to the satellite data.

Figure 20 shows that the 300-mb analysis was modified very little. The maximum change was less than 120 meters between the UNMOD and MOD ANALS. Slight changes in the analysis were made mainly to identify the troughs near

140° W and 178° W in order to maintain vertical consistency with the 500-mb analysis. Particular attention was paid to wind directions and gradients with more data available at 300 mb than on the 500-mb charts. An analyst must be careful to make modifications at 300 mb which do not violate conventional data.

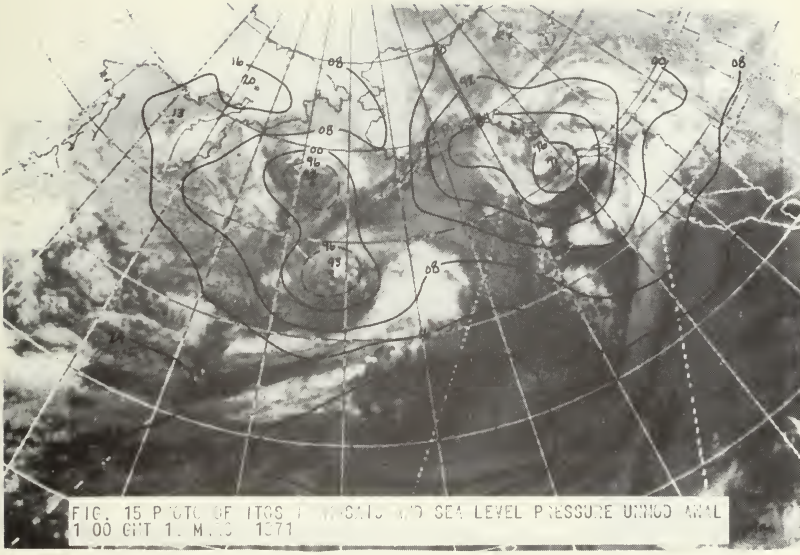


FIG. 15 PHOTO OF ITOS 1 MOSAIC AND SEA LEVEL PRESSURE UNMOD ANAL
1200 GMT 12 MARCH 1971

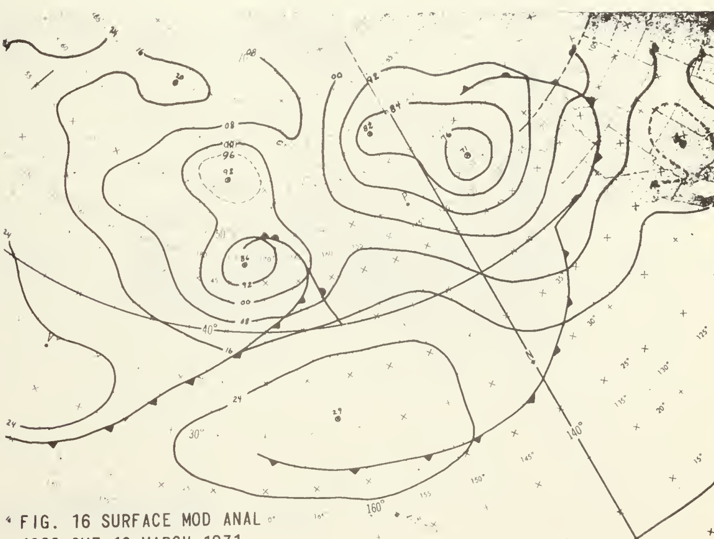


FIG. 16 SURFACE MOD ANAL
1200 GMT 12 MARCH 1971

FIG. 17 PHOTO OF ITOS [illegible] MOSAIC AND 500MB UNMOD ANAL
1200 GMT 1[illegible] MARCH 1971 SD ZERO LINE-DASHED WHITE

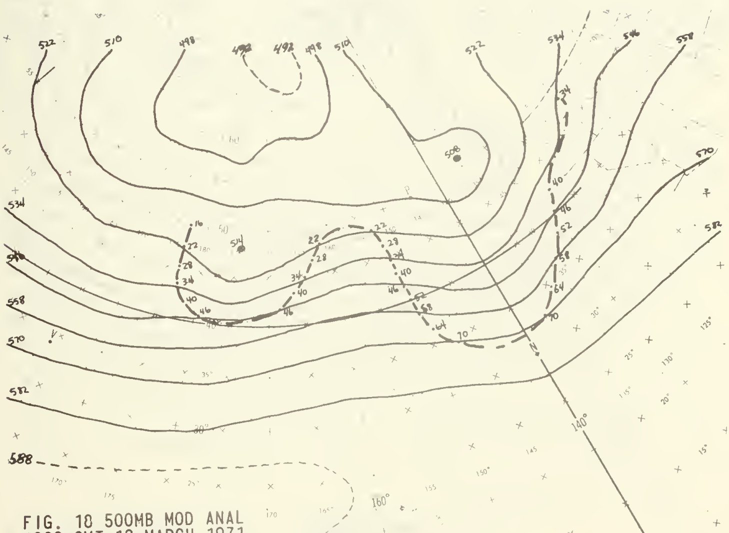


FIG. 18 500MB MOD ANAL
1200 GMT 12 MARCH 1971

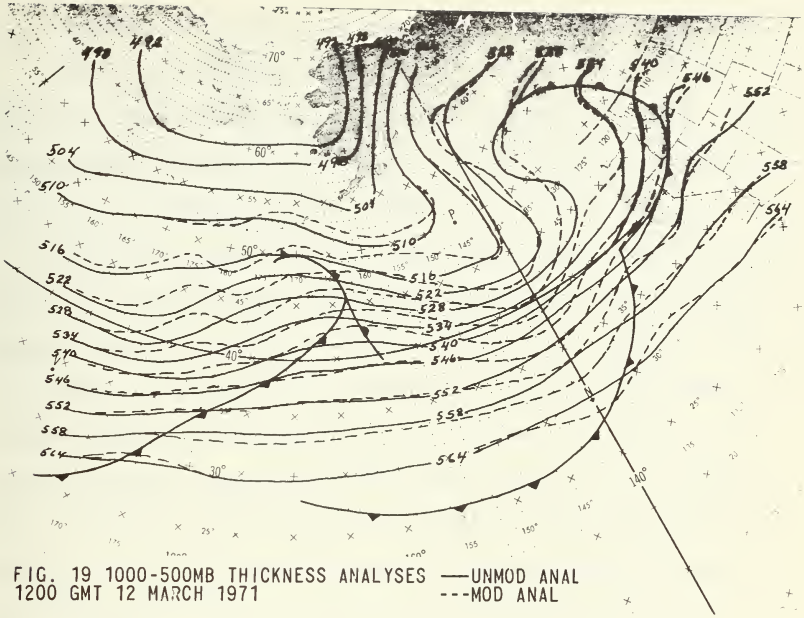


FIG. 19 1000-500MB THICKNESS ANALYSES —UNMOD ANAL
1200 GMT 12 MARCH 1971 ---MOD ANAL

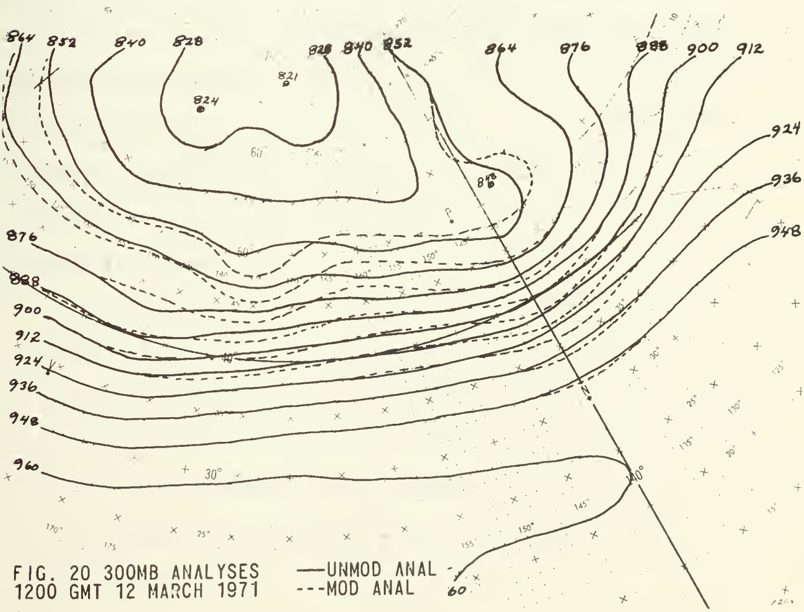


FIG. 20 300MB ANALYSES —UNMOD ANAL
1200 GMT 12 MARCH 1971 ---MOD ANAL

D. 0000 GMT 13 MARCH 1971 ANALYSES

There was excellent video coverage with good detail from the ITOS 1 Northern Hemispheric satellite mosaic. An abundance of surface ship reports were observed as expected during this midday synoptic time.

Figure 21 shows that the UNMOD sea-level pressure analysis was in fairly good agreement with the satellite mosaic except for the vortex near the center of the photo. The low center, now showing a 982 center, apparently moved nearly 700 miles during the past 12 hours, which doesn't seem plausible compared to the past history of the system. The MOD ANAL, shown in Fig. 22, depicts the modification made to this particular system and other minor changes to the analysis. The satellite mosaic indicates that the cloud vortex which was 47° N, 173° W at 1200 GMT 12 March is now centered near 46.5° N, 165° W, in good agreement with past movement of the system. However, a new vortex formed; its location is near 47° N, 156° W and the central pressure is estimated as 979 mb from ship reports. Surface winds of 50 knots were reported in the southwest quadrant of the system. The wave off the California coast occluded and developed rapidly as it moved northeast forming a double center over northern Nevada and along the Oregon coast as indicated by the satellite mosaic. The PVA MAX moved eastward to near 38° N, 130° W and the cloudiness appears to be enhanced over central California, indicating the development of a new wave on the front. The PVA MAX

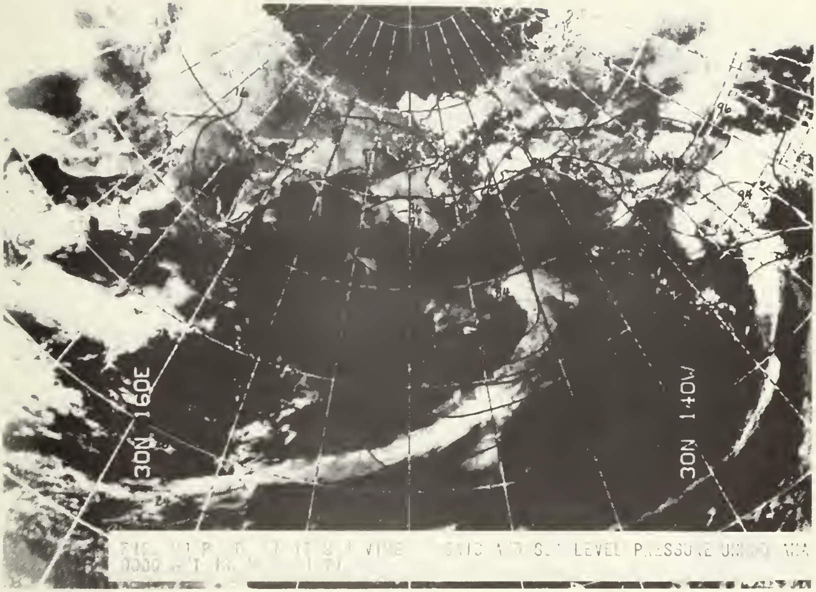
near 40° N, 173° E has not developed appreciably from the previous analysis.

Figure 23 shows that the 500-mb SD zero line is in much better agreement with the cloud patterns compared to the 1200 GMT 12 March chart, especially for the amplitudes of the systems, but there are still errors in location. The cloud pattern along 150° W between 40° N and 50° N indicates the zero line is too far to the east but the shape is nearly correct. The zero line also crosses the front off the California coast. The modifications to the zero line as well as some corrections in the 500-mb contours are shown in Fig. 24. The double 500-mb vortex near 160° W is indicated by the cloud patterns, reanalysis of upper air reports and past history, all of which led to considerable adjustment of the contours in this area. Again the trough was flattened on the UNMOD ANAL with the trough and ridge being moved too rapidly eastward. SINAP computations were made on the double center at 60° N, 159° W and 48° N, 164° W using regression equations. The changes were about -30 and -80 meters, respectfully, relative to the UNMOD ANALS.

Figure 25 shows that there is considerable improvement of the 1000/500-mb thickness patterns on the MOD ANAL. The thickness ridge over the frontal system in Oregon was smoothed considerably on the UNMOD ANAL but is plainly visible on the MOD ANAL. There was sufficient data here, but the computer was unable to formulate the correct

analysis. The big changes are over the central portion of the chart. There is a good thickness ridge over the rapidly developing frontal system on the MOD ANAL. The warm front location is in excellent agreement here. The modified thickness pattern over the frontal system is a result of major changes in both the surface and 500-mb analyses, namely the formation of a double vortex at both levels and considerable deepening of the centers at 500 mbs. The thickness trough near 163° W is nearly coincident with the 500-mb flow indicating that the 500-mb low at 48° N, 164° W is a cold low.

Figure 26 indicates very little change on the 300-mb MOD ANAL except near 45° N, 165° W. The major changes made at the lower levels are reflected here with the trough being deepened about 160 meters. The UNMOD ANAL indicates the trough near 157° W which is nearly over the 1000/500-mb thickness ridge and much too far east.



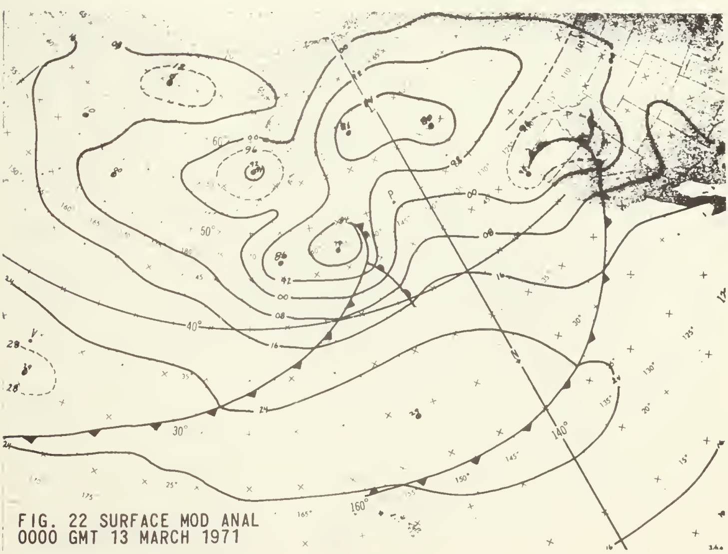
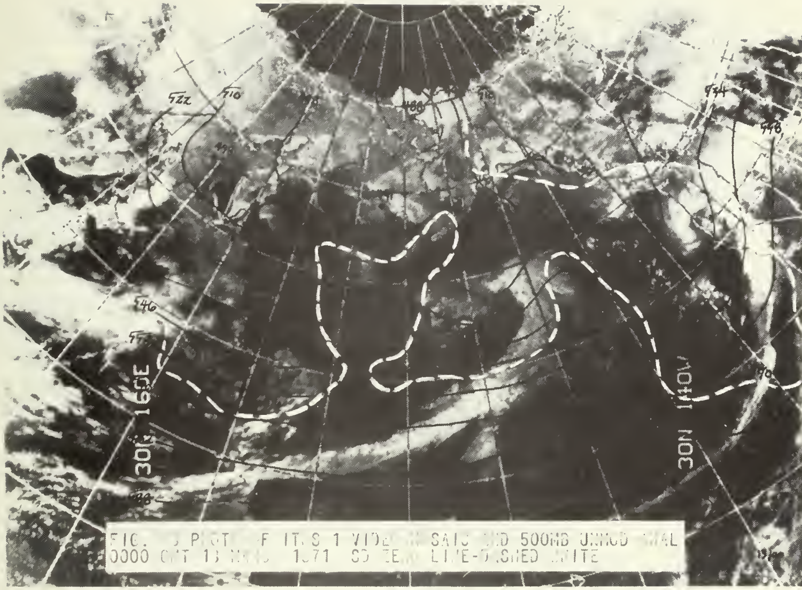


FIG. 22 SURFACE MOD ANAL
0000 GMT 13 MARCH 1971



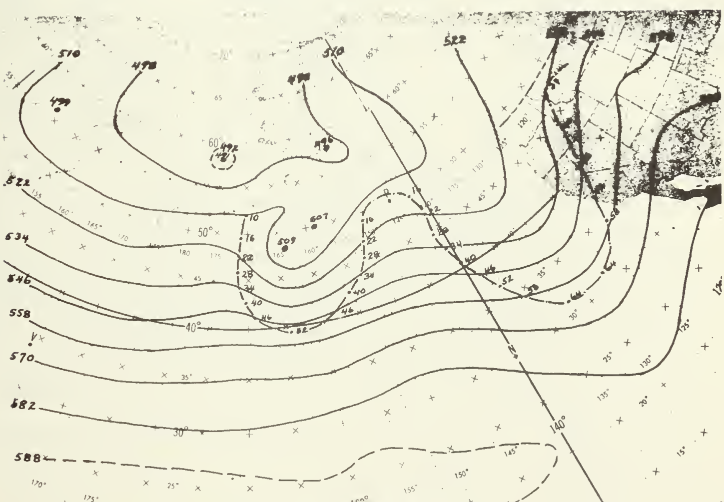


FIG. 24 500MB MOD ANAL
0000 GMT 13 MARCH 1971

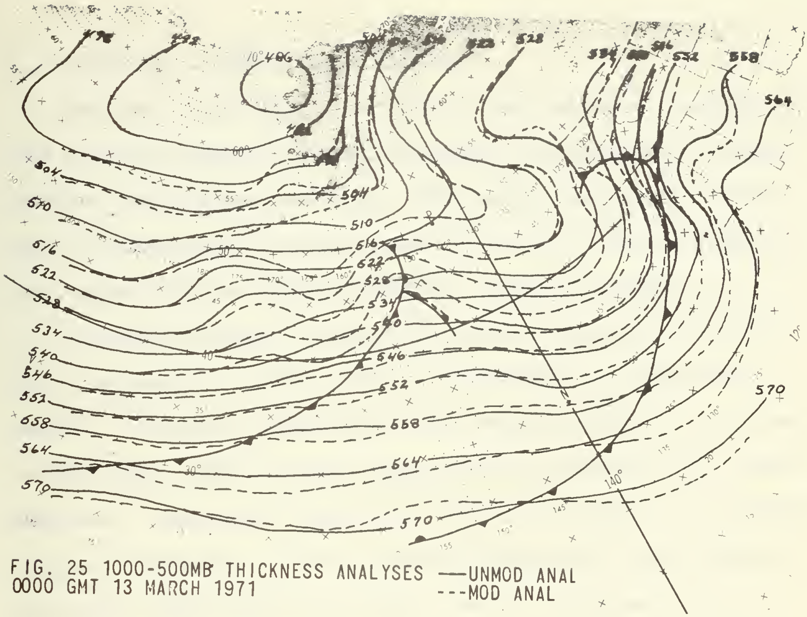


FIG. 25 1000-500MB THICKNESS ANALYSES —UNMOD ANAL
0000 GMT 13 MARCH 1971 ---MOD ANAL

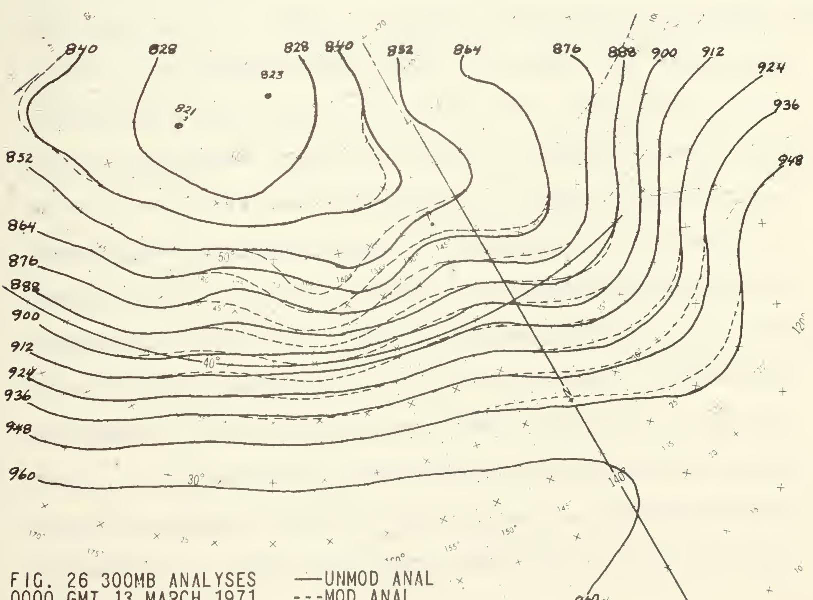


FIG. 26 300MB ANALYSES —UNMOD ANAL
0000 GMT 13 MARCH 1971 ---MOD ANAL

E. 1200 GMT 13 MARCH 1971 ANALYSES

The satellite mosaic of ITOS 1 IR nighttime viewing was the primary source for the following modifications to the surface and 500-mb analyses. The only ship reports available in the area of concern east of 170° E, for the upper air, were station ships NOVEMBER, PAPA and VICTOR.

Figure 27 shows the UNMOD sea-level pressure analysis which appears to agree very well with the IR satellite mosaic. However, there are a few modifications as indicated in Fig. 28. The low near ship PAPA has deepened to a mature cyclone. The center was moved from just south of ship PAPA to just northwest of this station ship due to the reported southwest wind which was deemed valid. The secondary low has become mostly low level and is barely discernable near 46.5° N, 151° W. There is a small area of high clouds just east of this center which helps to locate it, along with continuity. The wave on the cold front near 34° N, 163° W is very prominent on the IR with an extensive area of clouds with tops in the high troposphere. This indicates an unstable wave in the process of development. But the dry tongue on the trailing edge of the cloud band has not developed at this time. The PVA MAX near 40° N, 178° W shows classic development but is too far upstream for rapid development of the unstable wave during the next 12 hours. There is considerable cloudiness of a disorganized nature over the western Pacific with surface data supporting the formation of a weak low center near 41° N, 157° E. The

PVA MAX noted on the earlier charts apparently did not cause wave development over central California. The IR shows enhanced cloudiness over California but the surface data do not support the development of a wave in this area. The surface low near 56° N, 170° W, which resembles a PVA MAX, is maintained from past history, surface reports and the cloud pattern.

Figure 29 shows that the 500-mb SD zero line agrees very well with the general pattern of the clouds. A few typical modifications had to be made as shown by the modified analysis in Fig. 30. The zero line is adjusted over the wave near 163° W and along the front of the mature cyclone over the eastern Pacific. The result is a movement westward of both the trough near 140° W and the associated downstream ridge to agree with the cloud pattern. The vortex near ship PAPA required little or no modification based on the SINAP height computation, but is entered as a low center at 500 mb on the MOD ANAL. The short wave was deepened to agree with the PVA MAX near 178° W. The cloud pattern over the western United States was not considered in the modification of the 500-mb analysis as this area is not considered to be a sparse-data area.

Figure 31 shows that the 1000/500-mb thickness MOD and UNMOD ANALS are in much better agreement than on the previous analyses. The frontal system near 140° W is the primary feature at this synoptic time and is reflected by

a thickness ridge in both analyses. The UNMOD thickness positions the ridge east of the frontal system near 40° N, 135° W but west of the frontal system near ship PAPA while the MOD thickness is more consistent in showing enhancement of the thickness ridge over the frontal system. The trough behind the frontal system agrees very well with past history on the MOD ANAL. The 500-mb trough moved rapidly to the east during the past 12 hours reflecting the acceleration and deepening of the surface system which was indicated well by the FNWC analysis. However, the modification of the surface analysis, to include the secondary low-level system, resulted in a distinct thickness trough behind the front which enforces the concept of the cold low. The packing of the thickness pattern on the MOD ANAL reflects the surface wave observed near 34° N, 163° W.

Figure 32 shows that very little modification was made at 300 mb. Minor modification was necessary, with a maximum change of about 60 meters in the trough near ship PAPA. The intensity of the surface system and the modifications made at 500 mb suggests a more distinct trough at 300 mb as shown by the MOD ANAL.

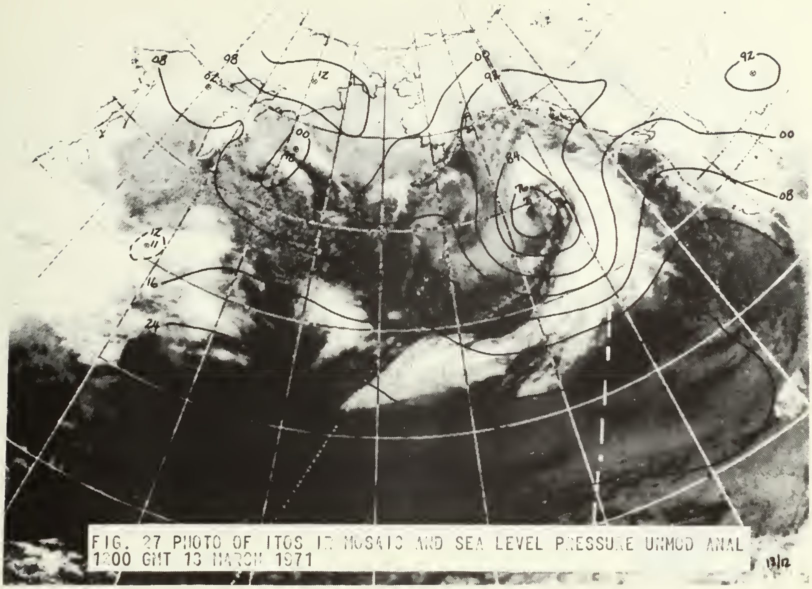


FIG. 27 PHOTO OF ITOS 1? MOSAIC AND SEA LEVEL PRESSURE UNMOD ANAL
1200 GMT 13 MARCH 1971

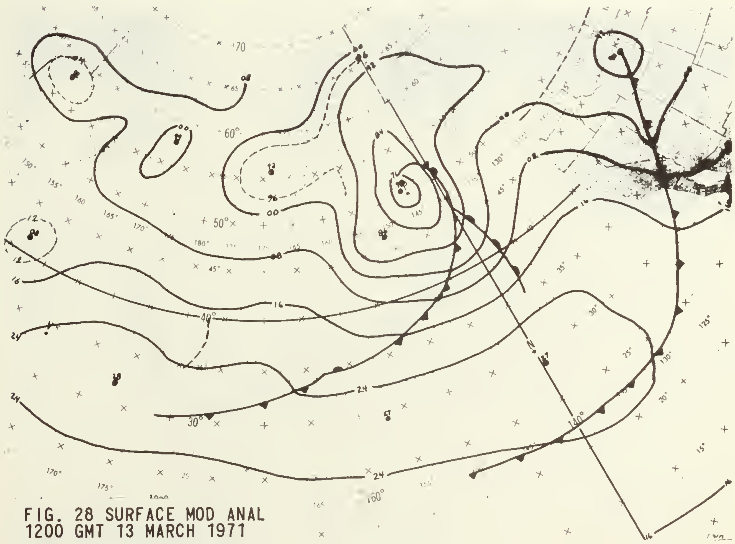


FIG. 28 SURFACE MOD ANAL
1200 GMT 13 MARCH 1971

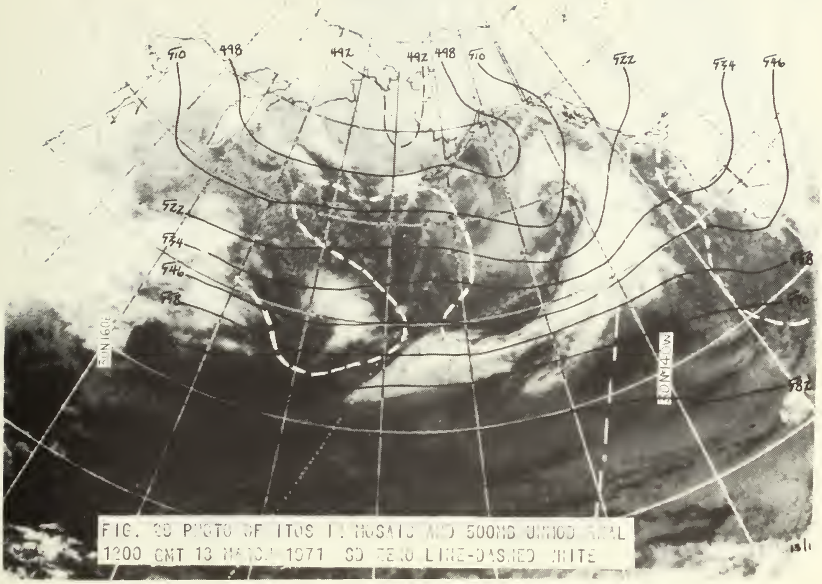


FIG. 29 PHOTO OF ITOS 1 MOSAIC AND 500MB UNMOD ANAL
1200 GMT 13 MARCH 1971 SD ZERO LINE-DASHED WHITE

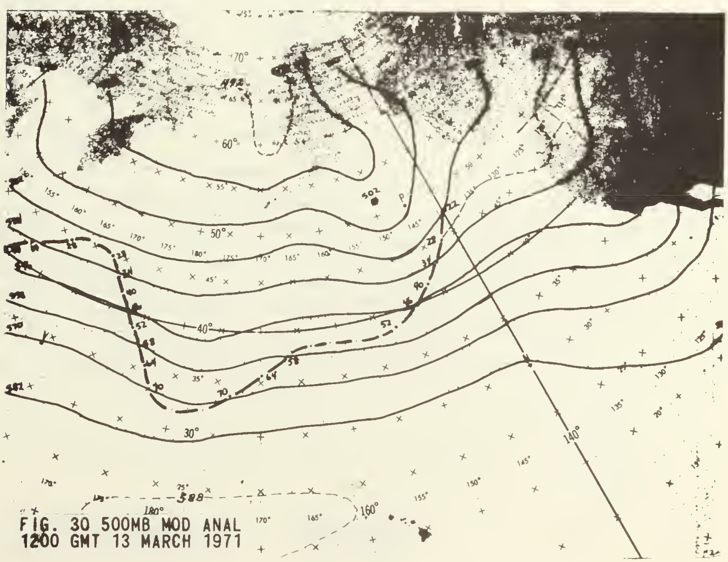


FIG. 30 500MB MOD ANAL
1200 GMT 13 MARCH 1971

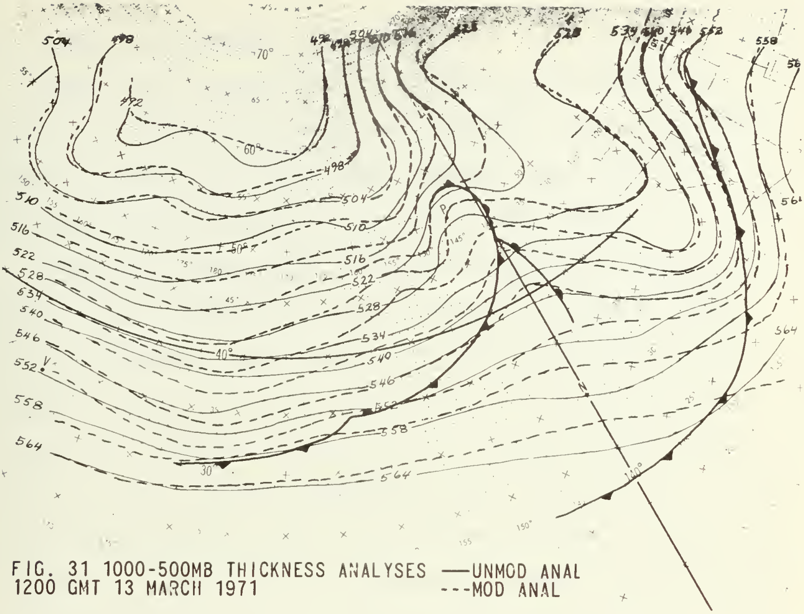


FIG. 31 1000-500MB THICKNESS ANALYSES —UNMOD ANAL
1200 GMT 13 MARCH 1971 ---MOD ANAL

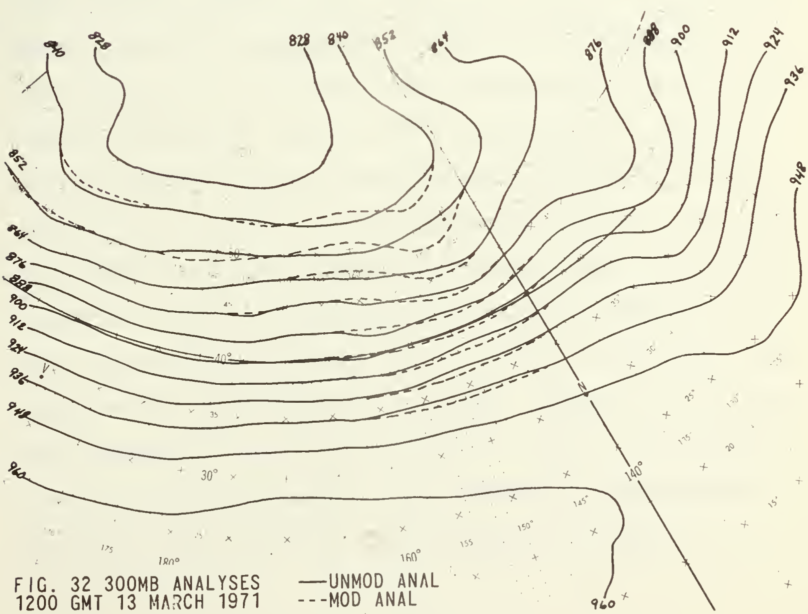


FIG. 32 300MB ANALYSES —UNMOD ANAL
1200 GMT 13 MARCH 1971 ---MOD ANAL

F. 0000 GMT 14 MARCH 1971 ANALYSES

There was an abundance of surface ship reports and excellent video coverage at this synoptic time. The FNWC 500-mb analysis over the area, however, was based mainly on the standard station ships and island reports.

Figure 33 shows good agreement between the satellite mosaic and the UNMOD sea-level pressure analysis except for the position and analysis of the deep mature cyclone over the eastern Pacific. The satellite mosaic clearly indicates a double vortex with the primary center near 52° N, 139° W and the secondary center near 47° N, 138° W. The modifications made to the analysis appear in Fig. 34. The FNWC analysis did not separate the small scale feature of the double vortex, but analyzed an elongated low, centered midway between them, near 49° N, 136° W. This complex low pressure system has reached full maturity as indicated by the dry tongue that completely surrounds the center, and should begin to fill on subsequent analyses. The associated frontal system extends southwest to the wave near 35° N, 153° W. This wave has shown no signs of development as might have been expected from the previous analysis. Close inspection of the cloud patterns will reveal that the PVA MAX near 40° N, 170° W is still too far upstream for development to proceed. However, a new bulge has appeared on the front near 32° N, 165° W and appears to be in ideal proximity to the PVA MAX for development during the next 12 to 24 hours near 35° N, 155° W.

Subsequent satellite data and analyses proved that the first wave did not develop while the second wave developed into a cyclone within 24 hours near 35° N, 150° W. A new family of cyclones appears to be developing over the western Pacific with the first vortex forming near 45° N, 167° E. The associated frontal system extends southwest to a developing wave near 37° N, 152° E. These systems are under very strong flow aloft in advance of the upper level trough, which is ideal for rapid development. Subsequent analyses showed that the wave developed into a 956-mb cyclone in less than 48 hours as it moved northeast to near 50° N, 170° W.

Figure 35 shows that the 500-mb SD zero line has little agreement with the cloud pattern except in the area surrounding the mature cyclone over the eastern Pacific, where minor adjustments also had to be made. The modified analysis (see Fig. 36) shows the changes made to the FNWC 500-mb analysis resulting from reanalysis of the zero line and SINAP computations. The zero line follows the frontal system southwest from the west coast of North America, over the wave and south of the PVA MAX near 170° W. Considerable adjustment is required over the western Pacific where it is difficult to correctly position the zero line due to the disorganized nature of the cloud patterns. The SINAP computation of the cloud vortex near 50° N, 140° W resulted in a 30 meter decrease in the 500-mb UNMOD height, with a slight displacement to the northwest for better vertical agreement. The trough along 135° W was moved about five

degrees westward and the trough deepened near 40° N, 170° W to agree with the PVA MAX. Anticyclonic flow was indicated between 40° N and 50° N near 175° W resulting in slight enhancement of the ridge on the modified 500-mb analysis. Note the strong gradient in the vicinity of 40° N and west of 170° E which corresponds to the area of bright cloudiness.

Figure 37 shows that there is still good agreement between the 1000/500-mb thickness UNMOD and MOD ANALS, especially over the eastern Pacific. The MOD ANAL shows only slight improvement over the frontal system north of 40° N near 130° W, but the packing behind the cold front to the southwest agrees more with the strength of the front as determined from the IR mosaic. The thermal trough near 170° W between 30° N and 40° N lies east of the surface high pressure center, reflecting cold, equatorward flow. The developing frontal system over the western Pacific is indicated by the thickness ridge near 45° N, 170°E and by the packing over the wave to the southwest on the MOD ANAL. These features are less pronounced on the UNMOD ANAL.

Figure 38 shows that the 300-mb analysis was modified over nearly the whole chart but the maximum change was only about 120 meters near 45° N, 175° E. The position of the troughs and ridges at 500 mb and the upper wind reports on the 300 mb were the basis for the modification.

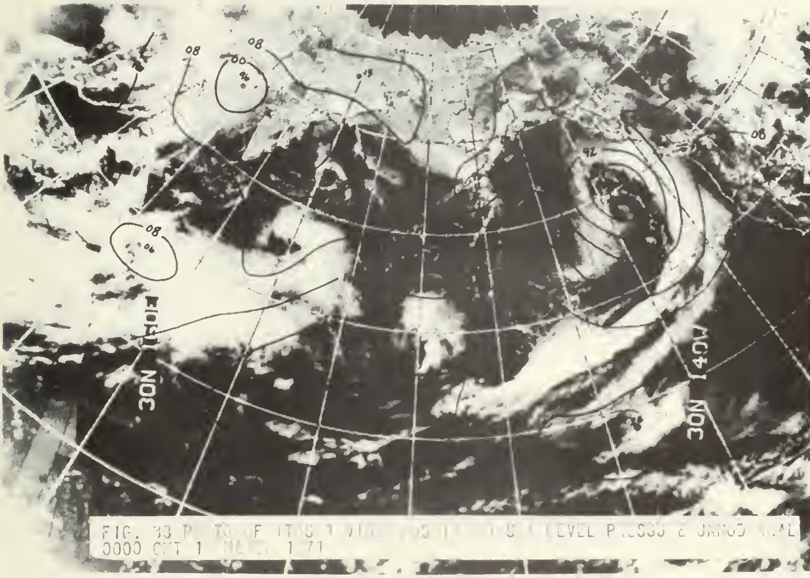


FIG. 33 P[illegible]TO [illegible]F IT[illegible]S 1 VID[illegible] [illegible] [illegible]SEA LEVEL PRESSURE UNMOD ANAL
0000 GMT 1[illegible] 1971

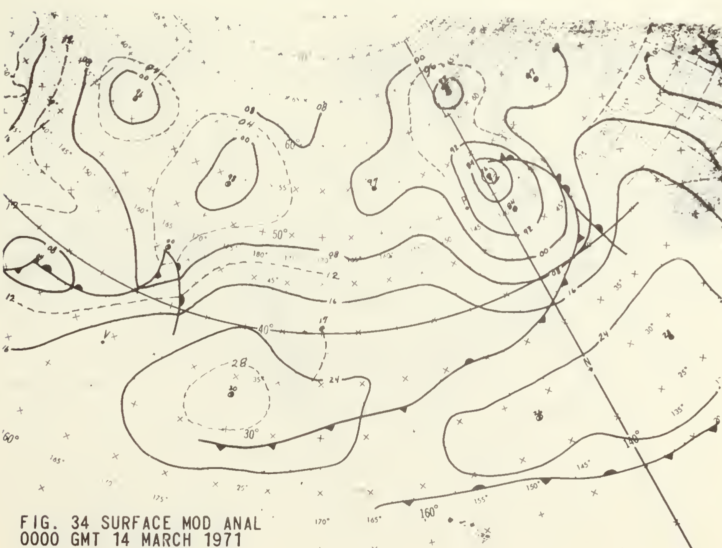


FIG. 34 SURFACE MOD ANAL
0000 GMT 14 MARCH 1971

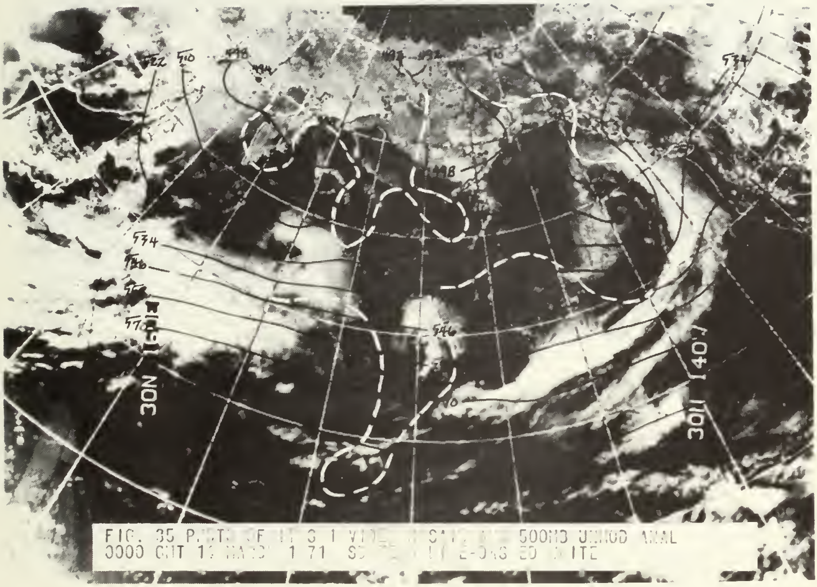


FIG. 35 PHOTO OF ITOS 1 VIDEO [illegible] 500MB UNMOD ANAL
0000 GMT 1[illegible] MARCH 1971 SO[illegible] LINE-DASHED WHITE

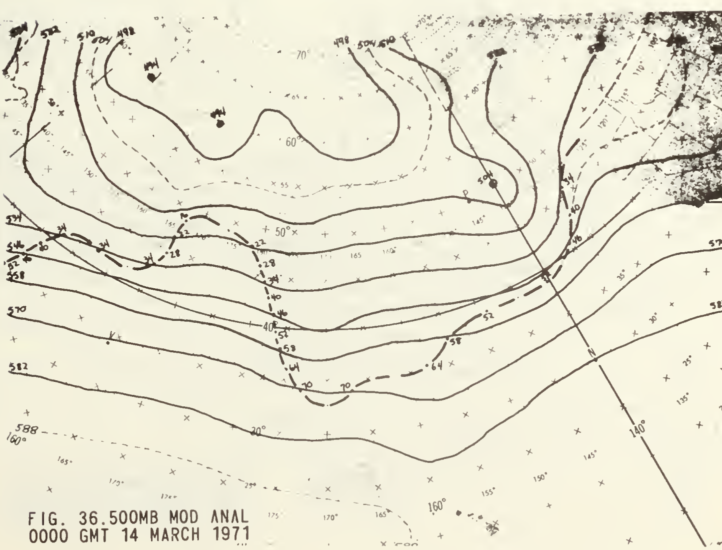


FIG. 36.500MB MOD ANAL
0000 GMT 14 MARCH 1971

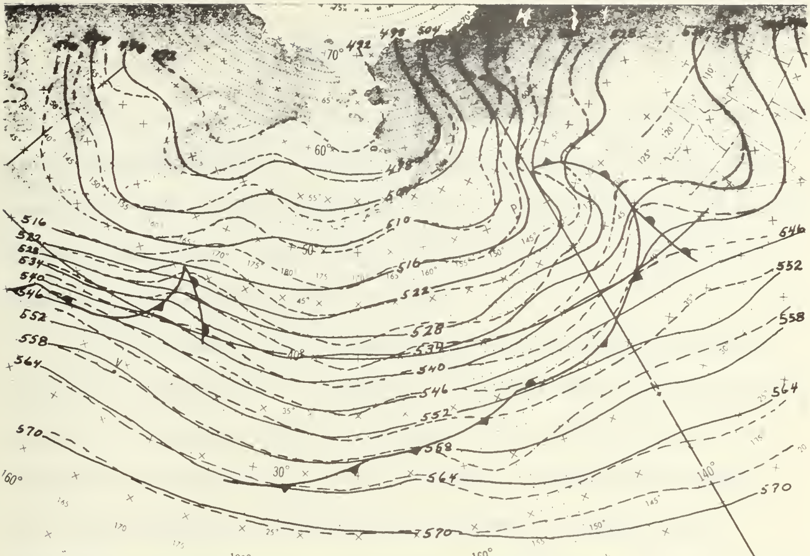


FIG. 37 1000-500MB THICKNESS ANALYSES —UNMOD ANAL
0000 GMT 14 MARCH 1971 ---MOD ANAL

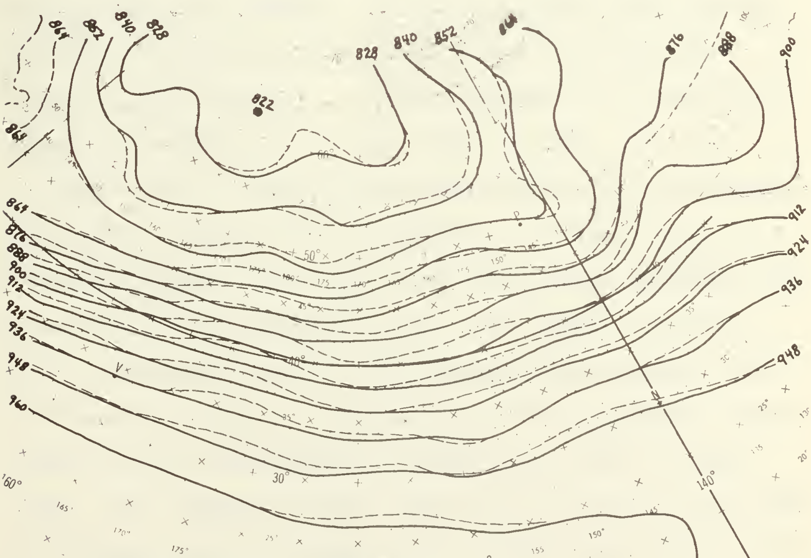


FIG. 38 300MB ANALYSES —UNMOD ANAL
0000 GMT 14 MARCH 1971 ---MOD ANAL

VI. RESULTS AND CONCLUSIONS

The case studies presented in section V yielded several significant results. Some were directly due to the two methods used in the modification of the analyses and a few were inferred or came about as an offshoot of different techniques or procedures tested.

It is evident that weather-satellite data provide excellent continuity of synoptic features and are invaluable aids in locating frontal systems over sparse-data areas. Figures 39 and 40 depict the frontal systems associated with the cyclones at different stages of development. Figure 39 follows the progression of a mature cyclone and its associated frontal system from the beginning to the end of the case studies. Figure 40 follows the development of a cyclone shortly after formation through its stage of full maturity. A third system in its beginning stages of development is also shown in Fig. 40. The various frontal systems were presented on separate figures to prevent confusion in overlapping. In every case of wave development there was a PVA MAX located upstream that came into close proximity to the cold front. The rule which indicates that as a PVA MAX approaches within 300-500 nautical miles of a frontal band the forecaster should watch for wave development, proved to be true in every case. For example the wave near 35° N, 163° W at 1200 GMT on 13 March did not develop when the PVA MAX remained over 600 miles upstream.

The Nagle-Hayden technique proved to be very workable. 500-mb heights derived from the adjustment of the SD zero line were taken as correct values and the analysis was modified accordingly. However, the estimate of the 500-mb heights at spiral cloud centers, as derived from the regression equations, had to be weighted and adjusted in nearly every case. Several subjective factors were considered in arriving at a reasonable value, namely, the stage of cyclone development, organization of cloud bands, and time and space continuity. The computations and interpretations of the 500-mb heights at spiral cloud centers proved to be the most difficult of the procedures tested. It is concluded, however, that with experience a well-trained cloud photo interpreter could use this technique to advantage. The ITOS IR mosaics proved to be very compatible with these techniques. In comparing the thickness patterns after the modifications were made, little difference was noted in the improvements made with video photos over those made with the IR. The 1000/500-mb thickness patterns were improved in every case where the 500-mb height field was modified. This demonstrates that quantitative use of satellite-observed cloud patterns can be made and that they permit the identification and location of short-wave systems in the 500-mb height field. It is emphasized again that the 1000/500-mb thickness analyses were performed after all modifications were made to the surface and 500-mb analyses and not used as an

integral part of the modified analysis. This was done to achieve a true evaluation of the Nagle-Hayden technique.

The ITOS IR satellite mosaics were invaluable in the study, giving nighttime continuity and an added dimension to several synoptic features including cloud-top heights which are indicative of frontal strength, wave development, height of closed cyclonic circulations, vorticity associated with the PVA MAX and indications of double-low formations. The only shortcoming noted on the IR photos was that the vortex center was often more difficult to locate than on the video photos, especially if it was a low-level system and not well developed.

Relatively few modifications were made to the analysis of sea-level pressure in comparison to the 500-mb level, yet the thickness patterns reflected improvements from changes at 500 mb. FNWC is currently inserting bogus reports in the surface analysis on a regular basis; little, if any, fabrication of data is done at the 500-mb level. It is suggested that the procedures used in this study cloud be applied at 500 mb or at the 300-mb level. With the withdrawal of station ship VICTOR (35° N, 165° W) from the data base in the western North Pacific Ocean this normally sparse-data area is even more void of conventional data; satellite input at the upper levels is a partial solution.

It is concluded that the 300-mb level is probably a better key level than 500 mb for SINAP even though all

modifications to the former were subjective in this study. Three sources of satellite data for 300-mb analysis exist, namely, SIRS heights and temperatures, winds from ATS cloud vector motion, and the Nagle-Hayden technique. These, coupled with the preponderance of AIREPS at 300 mb, qualify this level as the key level for tropospheric analysis. In this study the 300-mb level proved helpful in modifications at 500 mb. The added conventional data from AIREPS was useful in locating jet streams and determining gradients. Frequently, less modification was required at 300 mb than at 500 mb in the location of troughs and ridges and comparable height changes.

It was noted that the FNWC machine analysis generally analyzed a double cyclonic cloud vortex by a single low center. For example, a double vortex was clearly visible on the satellite photos at 0000 GMT 13 March and at 0000 GMT 14 March. Also, at this time low centers which still showed good organization on the satellite photo were prematurely dropped from the numerical analysis.

The analyst should make the minimum amount of change necessary to achieve meteorologically consistent patterns, both in time and space. More confidence may be placed in changes due to satellite data if the changes offset the characteristic errors of the numerical analysis (and prognostic) model. Until now the first-guess upper-air analysis has been a combination of the 12-hour barotropic prognosis and data received by 1½ hours after synoptic

time. Characteristically the barotropic model tends to move systems too fast north of the 500-mb maximum wind zone. This was also found to be true on the operational analysis (4½ hours after synoptic time) in almost every case, as manifested by the 500-mb SD zero line, located too far east on the analysis. This situation may be corrected by FNWC with a plan to utilize a combination of the 12-hour PE prognosis and an advective scheme to improve the first guess at 500 mb.

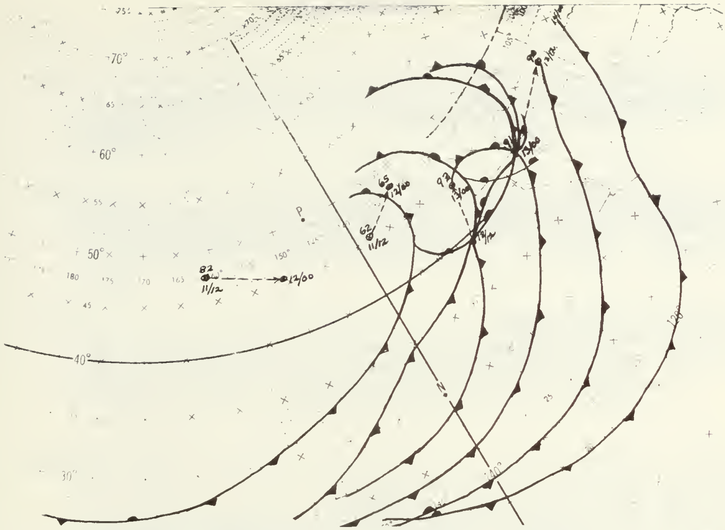


FIG. 39 TIME CONTINUITY OF SURFACE FRONTAL POSITIONS, EASTERN PACIFIC OCEAN AREA

FIG. 40 TIME CONTINUITY OF SURFACE FRONTAL POSITIONS, WEST AND CENTRAL PACIFIC OCEAN AREA

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13. ABSTRACT

The results of techniques and procedures used to evaluate the utility of satellite observations for enhancing the accuracy and detail of numerical analyses in sparse-data areas are presented. The experiments employed statistically-derived and subjective interpretations from video and infrared satellite data, for the purpose of modifying Fleet Numerical Weather Central's operational surface, 500- and 300-mb analyses. The resulting satellite-modified analyses for six synoptic times, in the period 11-14 March 1971, presents an implementation of satellite input to numerical analyses and prediction. The technology demonstrated here is offered as a guide to the man-machine approach to extratropical analysis as performed by major numerical weather centers.

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